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MARBLE

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MARBLE

by

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SUMMARY

The Bureau of Mines issued three Information Circulars on marble many years ago (5), (6), (7).[2] They have long been out of print; furthermore, conditions have changed considerably in the industry in succeeding years. A presentation of current data is therefore desirable. This report furnishes general information on marble, including its properties, distribution of domestic and foreign deposits, methods and equipment used in quarrying and milling, economic and marketing problems, and recent advances in marble technology.

INTRODUCTION

Most marbles are crystallized limestone. The term "marble" is derived from a Greek word meaning to sparkle or flash, because the calcite crystals in marble sparkle as they reflect light. The word "marble" is employed frequently to mean a small ball used in the game of marbles with which nearly every child is familiar. Although the little spheres were originally of marble, few of those made in recent years contain that material; nevertheless, the expression "playing marbles" has persisted.

In its geologic sense the term is applied to rocks comprising crystallized grains of calcite and/or dolomite. Marble has essentially the composition of limestone or dolomite, the chief difference being that the particles of calcium or magnesium carbonates in limestone usually are granular and noncrystalline. Most marbles are metamorphic rocks resulting from the recrystallization of limestone.

Commercially, the word has a wider use. As the ability to take a polish is the chief commercial asset of marble, all calcareous rocks that can be polished are classed as marbles. Furthermore, serpentine rocks that are attractive in color and pattern and can be polished are classed as marbles, although they may contain little calcium or magnesium carbonates.

COMPOSITION

Except for serpentine and other unusual varieties, virtually all marbles are calcium or magnesium carbonates. A calcite marble may contain 95 to almost 100 percent calcium carbonate ($CaCO_3$). A pure dolomite marble ($CaCO_3$, $MgCO_3$) contains approximately 54 percent calcium carbonate and 46 percent magnesium carbonate. Marbles of calcite and dolomite may contain 46 percent to almost no magnesium carbonate and 54 to almost 100 percent calcium carbonate. The principal commercial marbles of the United States are high-calcium type.

Virtually all marbles contain impurities. The more common impurities are silica (SiO_2), either as free quartz or combined in silicates; iron oxides, such as hematite (Fe_2O_3) and liminote (hydrous iron oxide); manganese oxide (MnO); alumina

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[2] Underlined numbers in parentheses refer to items in the bibliography at the end of this report.

(Al_2O_3) in the form of aluminum silicates; and sulfur, usually as pyrite (FeS_2). Small quantities of organic matter present in the original rock have been converted to graphite in the crystallization of the marble. Other minerals in marbles are mica, chlorite, tremolite, wollastonite, diopside, hornblende, tourmaline, pyrrhotite, sphalerite, and chalcopyrite. Impurities may take the form of veins, streaks, or cloudings having decorative effects. The white marbles contain few impurities.

Table 1 shows the chemical compositions of typical domestic marbles and is based chiefly on data compiled by Kessler (2). Verd antique marble contains chiefly serpentine. Pure serpentine contains 43 percent MgO, 44.1 percent silica, and 12.9 percent water. The verd antique listed in table 1 contains considerable alumina and iron. More than 7 percent CO_2 indicates magnesia present as carbonate. The constituents of the verd antique in table 1 add to less than 93 percent because the water of crystallization is not shown.

TABLE 1. - Chemical composition of commercial marbles, percent

Source	Type	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	CO_2
West Rutland, Vt.	Rutland Italian	55.86	0.34	0.06	0.02	-	43.78
Danby, Vt.	Danby	55.30	.41	.10	.03	-	43.72
Gantts Quarry, Ala.	White	55.19	.10	.16	.12	0.83	43.42
Regal, N. C.	Regal blue	53.70	.80	.06	.005	-	43.54
Phenix, Mo.	Napoleon gray ..	55.19	.40	.30	.03	-	43.25
Tate, Ga.	Etowah	53.23	.92	.94	.42	-	42.17
Do.	Creole	54.48	.90	.35	.04	-	43.22
Asbury, Tenn.	Appalachian gray	55.60	.07	.26	.06	-	43.58
Knoxville, Tenn.	Victoria pink ..	55.38	Trace	.14	.06	-	43.52
Holly Springs, Ga.	Verd antique ...	Trace	35.27	7.68	7.62	34.98	7.22

ORIGIN AND VARIETIES

Marbles may be classed in three groups:

The first, which includes by far the largest proportion of all marbles, comprises those resulting from the recrystallization of limestone. Most of these marbles are highly crystalline and usually white, although streaks or cloudings may be present. The bulk of the Alabama, Georgia, and Vermont marbles is of this type. The original rocks were formed in the sea, mainly as accumulations of the calcareous remains of marine organisms or as lime muds resulting from chemical precipitation. These original carbonates were consolidated to form coherent rocks, termed "limestone." The origin and character of limestone are described more fully in a Bureau of Mines report (11). Heat and pressure, accompanied by extensive deformation of the limestone beds, resulted in the highly crystalline character of commercial marbles. Fossiliferous or subcrystalline marbles have been subjected to less extreme metamorphism; in some instances included fossils remain almost intact. Such marbles have close enough texture to take a good polish, and the fossils add to their decorative qualities. The subcrystalline marbles seem to have been altered from limestone chiefly by circulating water, for they show no evidence of deformation or extreme pressure.

The second group comprises the onyx marbles. They consist essentially of calcium carbonate and are chemical deposits that have not resulted from metamorphism of preexisting limestones.

Onyx marbles result from processes of solution and precipitation. Calcium carbonate (limestone) dissolves very slowly in pure water but much faster in water charged with carbon dioxide. Thus carbonated springs may carry calcareous solutions. When these solutions reach the surface, the carbon dioxide is dissipated in the atmosphere; and, the solvent being lost, the calcium carbonate is precipitated. Impurities such as iron and manganese oxides may be present in varying amounts during deposition; consequently, successive layers may have different colors. Such banding gives beautiful decorative effects. Deposits of marble from cold-water solutions may be formed at the surface of the earth around exits of springs, or in rifts, cracks, or cavities in the rock through which the solution flows. Deposits may also take the form of stalactites, stalagmites, columns, or surface coatings in limestone caves. For this reason the rock is sometimes called "cave onyx."

Confusion exists in use of the term "onyx." True onyx is a banded chalcedony - a form of silicon dioxide related to jasper, agate, and flint. The calcareous rock was called onyx because its banding closely resembled that of the true onyx. To distinguish the calcareous from the siliceous varieties, the former is called onyx marble. It is sometimes called Mexican onyx because well-known deposits occur in Mexico.

A rock known as travertine is closely related in origin to onyx marble but is regarded as a product of precipitation from hot springs. Travertine is characterized by numerous irregular cavities, ranging from less than a pin head to more than 1/2 inch across. Travertines have attractive patterns and banding and, although generally not susceptible to high polish, are classed commercially with marbles by the Marble Institute of America.

The third type of marble comprises the verd antiques. The name is applied to marbles of prevailing green color, consisting chiefly of serpentine, a hydrous magnesium silicate. Verd antiques are highly decorative stones, the green being interspersed at times with streaks or veins of red and white. In no respect are they comparable with true marbles in either composition or origin. Serpentine usually results from alteration of basic igneous rocks such as the peridotites, which are rich in olivine or pyroxene, or from magnesium silicate rocks formed by metamorphism of impure dolomitic limestone.

PHYSICAL PROPERTIES

Hardness

Hardness may be defined as the resistance that the surface of a substance offers to abrasion. In Mohs' scale the hardness of calcite is 3 and dolomite, 3.5 to 4, whereas the hardness of window glass is about 6. Marbles are harder than most limestones because the grains usually are cemented together less firmly than those of marble, although they may consist of the same mineral, calcite. Hardness of a granular rock is measured by the degree of cohesion between grains rather than by the actual hardness of the mineral. The presence of impurities such as flint or silicate minerals may greatly increase the hardness of a marble. The hardness of a marble is a measure of its workability - an important property because the cost of quarrying marbles that are worked slowly by tools is much higher than the cost of working softer materials. Although the cost of quarrying hard marble may be high, hardness is a desirable property if the marble is to be exposed to abrasion. High resistance to abrasion and uniform hardness are desirable in marbles used for sills, steps, or floor tile, especially in public buildings where abrasion may be severe. In constructing floors of different marbles, it is important that the marbles be equally resistant to abrasion, otherwise the floor will become uneven. Standard tests to determine abrasive hardness apply only to areas exposed to foot traffic, not to wall areas.

Weight

Marbles range in weight from 165 to 180 pounds per cubic foot. By knowing the average weight per cubic foot, the quarryman can measure a block and calculate its weight with reasonable accuracy. The economic significance of weight is chiefly in connection with the necessary strength of equipment for handling and freight charges for transportation. The weight per cubic foot also provides a means of calculating the weight that base courses of high structures must bear.

Solubility

The solubility of marble deserves careful consideration if the marble is for exterior use, because all stones dissolve slowly when exposed to the atmosphere. Usually the rate of solution of marbles is extremely slow. Surface waters, which contain gases such as carbon dioxide, dissolve marbles to a limited degree. Near large cities or industrial plants various acids in smoke are absorbed by rainwater and increase its dissolving power. The rate of solution varies in different marbles, depending upon chemical composition, texture, and permeability. Marbles with low water absorption are best for exterior use.

Color

The color of a marble, one of its most important physical properties, is governed by the nature of the constituents. Marbles of almost pure calcite or dolomite are white, whereas the prevailing color of verd antique marbles is green. Variations from whiteness are due to admixtures of foreign materials. The impurities may be distributed uniformly, giving uniform coloration, or they may be present in bands or streaks, giving clouded or nonuniform colors. Beautiful banded effects are obtained by sawing veined marbles in certain directions. The causes of most colors in marbles are easily determined. Black and gray shades are attributed to carbonaceous matter, which is usually present as fine scales of graphite; red, pink, or reddish brown is due mainly to the manganese oxide or hematite; and yellow-brown, yellow, or cream is caused by minute grains of limonite, a hydrous oxide of iron. Lenses and bands showing a bluish tint found in some beds of white marble are difficult to explain. Highly colored marbles are usually, but not always, ones that have been brecciated or fractured, subsequent consolidation being accompanied by infiltration of coloring material, and are mostly of foreign origin. Each bed in a marble deposit shows more or less color uniformity; therefore, uniform colors usually can be obtained by working each bed separately.

Translucence

Translucence is the capacity of marbles to transmit light. The more translucent varieties, if fine grained, are well adapted to making novelties, statuary, or other ornaments. The waxy appearance of some marbles seems to be related to translucence. The depth to which light will penetrate the best statuary marbles ranges from 1/2 to 1-1/2 inches.

Texture

The term "texture" as applied to marble means size, degree of uniformity, and arrangement of constituent minerals. Grains of calcite (the chief constituent of most marbles) are crystalline and have a definite cleavage, showing bright reflecting faces on a broken surface. In most marbles the cleavages appear about equally prominent in every direction. In some marbles, however, the gains are elongated in one direction by the folding or plication of beds. The size of grain is commonly described as fine, medium, or coarse. Most commercial marbles have a uniform texture, but some colored marbles, especially the imported types, show striking variations.

Rift or Grain

The terms "rift" and "grain" are synonymous, as applied to marble, and mean the direction of easiest splitting. Usually the rift parallels the bedding and probably is due to elongation of grain caused by pressure. Rift may be emphasized by the presence of platy or fibrous minerals, such as scales of mica or graphite or needles of actinolite. These scales or needles usually have their long axes parallel to the direction of grain elongation and thus increase the tendency of the marble to split in that direction. Quarrymen find it advantageous to follow the direction of easy splitting, because drill holes for wedging may be spaced farther apart.

Porosity

Porosity is the volume of pore space expressed as a percentage of the volume of a mass of rock. The pore space of high-grade marbles is usually very small, ranging from 0.0002 to 0.5 percent. Low porosity in exterior marble is desirable, because pores permit infiltration of water that may discolor the stone or cause disintegration by freezing. Porous stones also collect soot or particles of soil when exposed to smoke or dust and may become moss covered. Virtually all domestic marbles recommended for exterior use have low porosity.

Strength

The strength of marble is a measure of its capacity to resist stresses and depends partly on the rift and cleavage of the grains and partly on the degree of cohesion, interlocking of grains, and nature of any cementing material present. Compressive, transverse, tensional or cohesive, and shearing strength all affect use, but compressive strength is the quality commonly tested. Usually marble is stronger across the bed than parallel to it. Table 2 shows the compressive strength of common commercial marbles. As the weight imposed on the base course of the Washington Monument, Washington, D. C., is less than 700 pounds per square inch, the figures in this table show that any of the standard commercial marbles can support many times the weight of superimposed materials in structures in which they are ordinarily used. Most marbles can also withstand any transverse or shearing stresses to which they may be subjected; however, some brecciated or veined marbles are too weak to sustain heavy loads. Strength has no sifnificance in judging the quality of cemetery memorials.

Jointing or Unsoundness

The term "unsoundness" refers to all cracks or lines of weakness in marble other than bedding planes. The various types are known locally as joints, headers, cutters, hairlines, slicks, seams, slick seams, dry seams, or dries and cracks. Joints in most marble deposits are straight and uniform, although in some deposits they are curved or irregular. Some are open and conspicuous, and others are so obscure that they are difficult to recognize. The spacing of joints varies. In some deposits, joints may be 10 to 30 feet apart; in others, they may be separated by only a few inches. Wide spacing adds greatly to the value of a deposit.

TABLE 2. - Compressive strength of marbles, pounds per square inch[1]

Variety	Location	Average compressive strength	
		On bed	On edge
Alabama white	Gantts Quarry	14,744	11,456
Creole	Tate, Ga.	11,636	11,908
Etowah	do.	11,545	10,194
Napoleon gray	Phenix, Mo.	11,773	12,261
Regal blue	Regal, N. C.	15,598	13,908
Tennessee marble	Amaico, Tenn.	17,664	16,570
Appalachian gray	Asbury, Tenn.	18,274	-
Danby	Danby, Vt.	10,691	10,558
Pittsford Italian	West Rutland, Vt.	14,269	14,797

[1] Kessler, D. W. Physical and Chemical Tests of the Commercial Marbles of the United States: Nat. Bureau of Standards Tech. Paper 123, 1919, pp. 35-36.

Joints probably are caused by strains in the rock mass. A compressive force in one direction tends to develop two systems of joints at right angles to each other and at angles of 45° to the line of pressure. Therefore, two systems of joints at approximately right angles are not uncommon. Such a systematic arrangement of joints is recognized by most quarrymen and is an important factor in the economy of marble working. Waste may be minimized by maintaining quarry walls parallel with the major joint systems. All cuts should be directed and spaced so that seams will intersect blocks as little as possible. Blocks intersected by oblique joints are virtually useless.

CHIEF IMPURITIES IN MARBLE

Iron Sulfides

The iron sulfies, pyrite and marcasite, are present in most marbles. These sulfides have the same chemical composition (FeS_2) but differ in crystal form. Pyrite is the most common. It may appear as scattered crystals or as bands and masses. Decomposition of the sulfides to oxides may cause discoloration. Although marble containing pyrite is generally condemned for exterior use, some marbles containing pyrite crystals will withstand weathering for many years without noticeable staining. Marble containing pyrite may be used to advantage for interior structural or ornamental purposes. The yellow pyrite may produce decorative effects on polished surfaces; however, the extreme hardness of the pyrite may make cutting difficult and may injure tools. Moreover, the great difference in hardness between the pyrite and the marble may result in uneven surfaces during grinding and polishing.

Silica

Although most marine shell accumulations are calcium carbonate, a few organisms (such as radiolaria and diatoms) secrete siliceous materials, and such skeletal remains in the original limestone may cause knots or bands of silica in marble. Silica may also be introduced into a marble bed later in the history of the deposit. Water percolating through fissures sometimes contains small quantities of silica in solution, which may be precipitated in cracks and cavities. This silica tends to follow unsoundness and may even seal fractures. Silica usually detracts from the appearance of a marble; occasionally, however, flinty masses result in decorative markings that are an asset to the stone. As silica is at least twice as hard as marble, its presence impairs workability. Moreover, uniformity of finish under a buffer is difficult to obtain on the surface of a flinty marble because of the unequal hardness of the constituents.

Silicates

Silica not only may be present in the free form, as discussed in the preceding paragraph, but also may be combined with other elements to form silicates such as pyroxenes, amphiboles, mica, or chlorite. The term "silicated" is applied to marbles containing silicates. In some marbles the silicates conform with the bedding and are not serious imperfections; they may even facilitate quarrying. When scattered throughout the mass in dark bands and patches, silicates may detract from the quality of the stone, although some clouded marbles are adapted to ornamental use.

MARBLE PROSPECTING

Limestone is usually converted into marble by intense pressure and folding. Thus, the attitude or thickness of a bed may change abruptly, either laterally or vertically. On this account, marble beds are more uncertain in position and extent than flat-lying limestone or sandstone beds, and careful prospecting is essential to successful marble quarrying. It is unwise to proceed with development work or with the extension of openings without reasonable assurance of a mass of sound, attractive marble uniform enough in quality and abundant in supply for profitable exploitation.

By study of rock exposures a geologist may learn the chief structural features and thus determine the position, thickness, and attitude of the beds with fair accuracy. Geologic maps are valuable in determining the position of marble beds beneath the surface and in gaining information as to their extent. However, knowledge obtained from surface exposures and geologic maps is insufficient. The nature and quality of the rock and extent of reserves can be determined definitely only by core drilling. Cores will supply information on color, texture, and uniformity, on the thickness of the bes, and on their soundness. The larger marble companies conduct extensive core drilling before developing new deposits or enlarging their quarries or mines.

ECONOMIC CONDITIONS

The success of a marble enterprise depends upon several important considerations, apart from the quality and size of the deposit. A wise prospective marble producer gives careful consideration to market demands, prices, transportation facilities, competitive conditions, availability of labor, wage scale, and other economic questions for which a reasonably satisfactory answer should be obtained before large expenditures are made. Many enterprises have failed because these matters have not been fully studied.

USES

Marble is used mainly for buildings and monuments, interior decoration, statuary, and novelties. For exterior use in buildings, qualities of endurance are as important as appearance. The marble should be strong, uniform, close grained (although not necessarily fine grained), reasonably nonabsorptive, and free from impurities that might stain the surface by weathering. Uniform color is sometimes required, but a blending of colors may be desirable. High-grade exterior marbles are very enduring. A good example is the Taj Mahal in India, built more than 300 years ago.

For interior use, appearance is of prime importance. Both white and colored marbles are used for floors, steps, baseboard, columns, balusters, wall panels, wainscoting, and arches. Marbles used for floors and stair treads comprise varieties reasonably resistant to abrasion. Brecciated, colored marbles, of which virtually all are imported, are used widely for columns, wainscoting, and veneer, some of which may require reinforcing. Verd antique is popular for interior decoration, and some types are used for exteriors. Onyx marble and travertine are well suited for interior decoration. They have a waxlike appearance and attractive banding.

Statuary marble is the most valuable variety. It must be pure white, uniform, and usually fine grained, although some coarse varieties carve exceptionally well. Numerous statuary and decorative marbles from United States quarries are now on the market, and each has its distinctive trade name.

The more ornamental types are used for novelties. Onyx marble, verd antique, and others are made into inkwells, lamp bases, ashtrays, clockcases, paperweights, book ends, and various other gift-shop novelties. Marble tabletops that were used extensively many years ago have again attained wide popularity. The uses of waste marble are given later in this paper under Waste in Quarrying and Manufacture.

HISTORY OF PRODUCTION

As shown in table 3, marble quarrying was a larger industry many years ago than it is today. The use of solid marble walls virtually ceased with introduction of steel-framed reinforced construction, and so-called marble buildings thereafter had only a thin marble veneer.

Sales of building marble declined greatly during the industrial depression of the early 1930's and dropped even lower during World War II, when construction of buildings that use marble was virtually at a standstill. Postwar recovery has been moderate. Sales of memorial marble maintained a relatively high level during World War II and the early postwar years but thereafter declined greatly.

EMPLOYMENT DATA

According to statistics compiled by the Bureau of Mines, the marble industry, comprising 53 operating plants, had a total working force of 2,510 men in 1956. Of this total, 975 worked in and about the quarries and 1,535 at outside plants, chiefly on marble dressing. Labor performed during the year totaled 5 million man-hours, an average of 2,103 hours per man. The plants were active for an average of 253 days per employee, the weighted average length of shift being 8.31 hours. Accidents at these establishments resulted in 1 fatality and 191 injuries.

Data on employment inside the quarries show that 975 men were employed in 46 marble quarries in 1956. Working shifts averaged 8.34 hours, and man-hours worked totaled 1,937,609. During the year there was 1 fatality and 105 nonfatal injuries due to accidents.

Table 4 shows total employment in the marble industry over a period of years.

TABLE 3. - Production of marble in the United States, 1930-56

Year	Building stone		Memorial stone		Total	
	Cubic feet	Value	Cubic feet	Value	Cubic feet	Value
1930	2,471,000	$9,076,031	870,270	$3,263,383	3,341,370	$12,339,414
1931	1,661,350	7,842,496	637,830	2,177,656	2,299,180	10,020,152
1932	1,681,850	5,627,602	432,590	1,669,689	2,114,440	7,297,291
1933	1,344,310	4,877,738	426,300	1,358,770	1,770,610	6,236,508
1934	500,010	1,719,456	464,910	1,475,426	964,920	3,194,882
1935	368,450	1,706,270	300,370	1,521,681	668,820	3,227,951
1936	771,960	3,780,874	374,520	1,751,947	1,146,480	5,532,821
1937	731,700	3,336,545	360,580	1,798,176	1,092,280	5,134,721
1938	687,290	3,264,877	358,390	1,708,188	1,045,680	4,973,065
1939	1,046,830	4,704,047	411,360	1,601,032	1,458,190	6,305,079
1940	782,600	3,324,029	269,870	1,471,074	1,052,470	4,795,103
1941	511,810	2,748,572	305,760	1,621,649	817,570	4,370,221
1942	278,460	1,567,736	294,610	1,883,994	573,070	3,451,730
1943	137,800	822,853	373,320	2,256,639	511,120	3,079,492
1944	178,170	1,065,638	432,370	2,801,844	610,540	3,867,482
1945	265,500	1,573,148	438,110	3,132,284	703,610	4,705,432
1946	422,880	3,079,553	483,180	4,001,462	906,060	7,081,015
1947	501,590	4,276,453	509,410	4,960,625	1,011,000	9,273,078
1948	576,500	5,022,973	397,260	4,082,470	973,760	9,105,443
1949	844,740	7,494,892	352,720	3,657,710	1,197,460	11,152,602
1950	755,070	6,528,013	296,120	2,878,374	1,051,190	9,406,387
1951	783,861	6,659,913	242,553	2,244,771	1,026,414	8,904,684
1952	763,770	6,620,584	284,695	2,658,634	1,048,465	9,279,218
1953	634,333	5,975,453	263,103	2,455,049	897,436	8,430,502
1954	754,282	7,192,409	241,320	2,662,453	995,602	9,854,862
1955	1,005,127	9,213,268	359,931	3,321,699	1,365,058	12,534,967
1956	981,887	8,837,470	257,925	3,260,527	1,239,812	12,097,997

TABLE 4. - Employment in the marble industry, 1930-56

Year	Number of employees	Year	Number of employees
1930	6,087	1944	1,450
1931	4,654	1945	1,748
1932	4,286	1946	2,370
1933	4,117	1947	3,165
1934	2,488	1948	2,747
1935	2,441	1949	2,815
1936	3,304	1950	2,600
1937	3,647	1951	2,584
1938	3,414	1952	2,376
1939	3,697	1953	2,442
1940	3,240	1954	2,558
1941	2,693	1955	2,221
1942	2,205	1956	2,510
1943	1,540		

DISTRIBUTION OF DEPOSITS

Domestic Deposits

General

As most marbles are formed as a result of regional and contact metamorphism acting upon preexisting limestones, the deposits are confined chiefly to areas of extreme folding or igneous intrusions; hence, most deposits are in mountainous regions. Important marble belts of the United States are the Appalachian region of the Eastern States and the Rocky Mountain and Coast Ranges of the West. Deposits also occur in the Central States and Alaska.

The Appalachian belt, which is the most productive, follows a comparatively narrow, well defined course, as shown in figure 1. Beginning at the Canadian border in northern Vermont, it extends due south through western Massachusetts and Connecticut and eastern New York almost to New York City. It appears again in western New Jersey and southern Pennsylvania and extends southwestward through Maryland, Virginia, North Carolina, Tennessee, Georgie, and Alabama.

In the Central States marbles occur in isolated localities, principally in Missouri and Texas where the original limestone has crystallized with little deformation of the beds. Various types of marbles occur in the Rocky Mountains and along the Coast Ranges, particularly in California, Nevada, Montana, and Colorado, but many deposits are too inaccessible to have commercial importance at this time.

Distribution by States

Alabama

The principal marble belt of Alabama passes through southern Talladega and northern Coosa Counties. It is about 35 miles long and has a maximum width of 1-1/2 miles near Sylacauga. The marbles range in geologic age from Middle Cambrian to Middle Ordovician. On the southeast, the belt is bordered by the Precambrian Talladega slate or phyllite, and, for most of its length on the northwest, by Ordovician Knox dolomite.

The best marble beds are 200 feet or more thick and dip about 30° southeast toward the slate. Intense compression and folding are evident; consequently, definite systems of joints have been developed. In places irregular, radial, and closely spaced joints result in a high percentage of quarry waste.

Most Alabama marbles are white, and some beds furnish pure, flawless material of statuary grade. Alabama marbles are somewhat finer grained than Vermont marbles and much finer grained than most Georgia marbles. Layers of light-green talc and schist give ornamental patterns or clouding to some varieties. Marbles from some beds are translucent. These marbles were used for the so-called transparencies in the roof of the Lincoln Memorial, Washington, D. C. Porosity is low, averaging about 0.5 percent according to National Bureau of Standards tests, with a somewhat lower percentage for varieties best adapted for exterior use. The marble is notably pure, containing 98 to 99 percent calcium carbonate.

The most productive regions are Gantts Quarry and Sylacauga, Talladega County, where large open-pit and underground openings have been made. At Gantts Quarry, diagonal jointing predominates; about 15 beds have been worked, each 4 to 11 feet

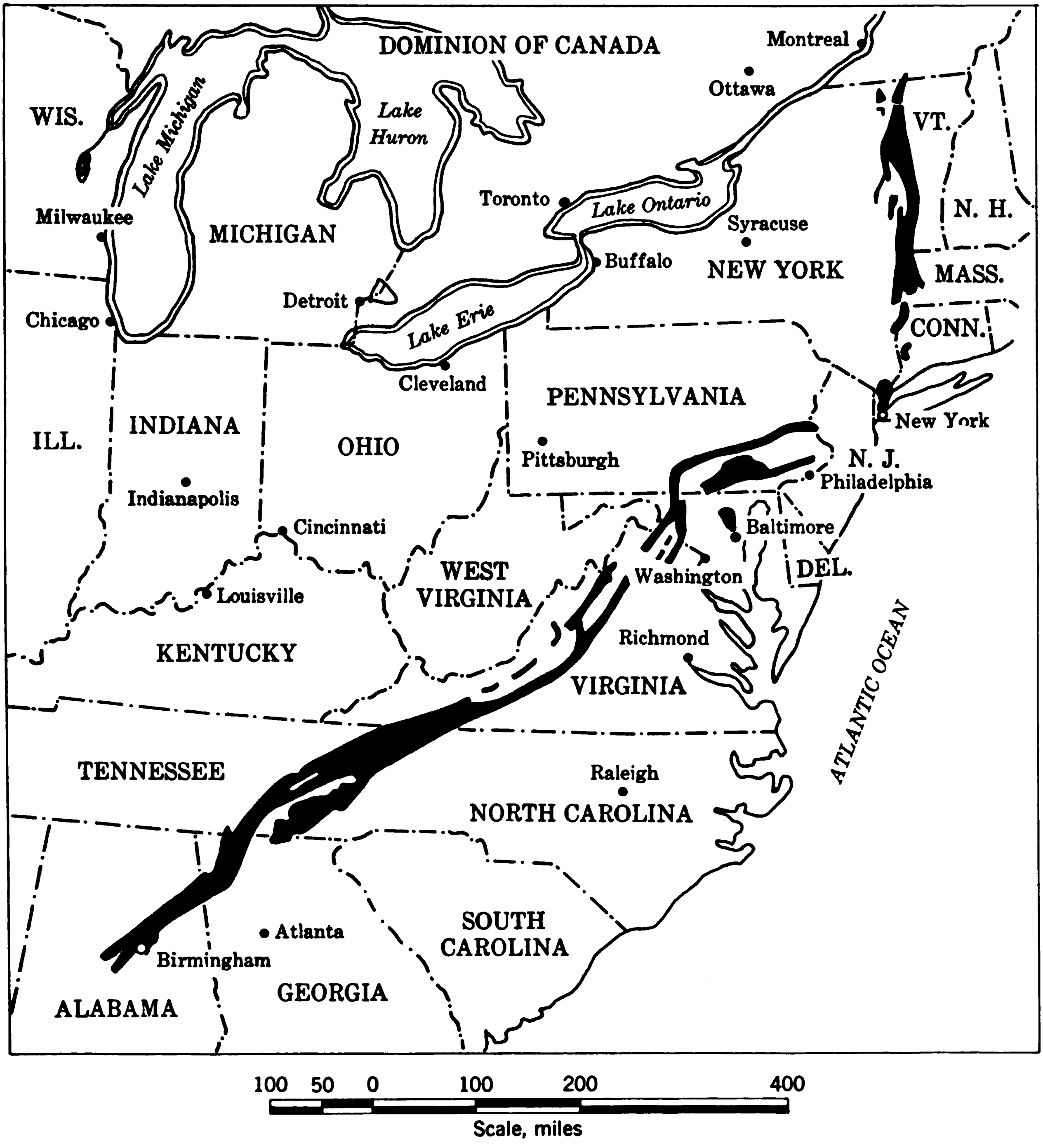

Figure 1. - Marble deposits in the eastern United States.

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thick. Because of differences in color and texture of the beds, several standard types are produced. In mills adjacent to the quarries, the marble is manufactured into finished products, chiefly for use in building.

Waste marble is ground into a very fine powder for use as whiting and as a constituent of such products as paint and stock feed.

A second large quarry is about 3/4 mile northeast of Gantts Quarry. Here, most joint planes parallel the dip and strike, but occasional diagonal joints result in considerable waste. Some beds are clouded; others are uniform and creamy white.

Alaska

The marble deposits of southeastern Alaska have been described in some detail (3). Quarries were operated years ago at Tokeen on Marble Island and Calder on Prince of Wales Island. The Calder quarry is on a bluff about 100 feet above sea level. Metamorphism of the original limestone probably was caused by the intrusion of a granite that lies northeast of the marble. The deposit is said to be large. Three types of marble were quarried - a pure white (the most valuable), a blue-veined white, and a light blue or mottled variety. The white marble ran more than 99 percent calcium carbonate. The Tokeen quarry furnished white, blue-black, and gray marbles. The marble blocks from both quarries were shipped to finishing mills at Tacoma, Wash., and other points on the Pacific coast. No production has been recorded since 1938.

Arizona

Onyx marbles are the chief types obtainable in Arizona. Highly ornamental white, green, and red marbles occur at Mayer, Yavapai County. Another deposit, comprising boulders of calcite and aragonite in soft travertine, is west of Cave Creek, Maricopa County. No production has been reported from these deposits since 1940. Small sales of marble were reported from Cochise and Pima Counties in 1954 for rough building construction and roofing granules.

Arkansas

The best-known marbles of Arkansas occur in the Boone formation of Lower Carboniferous age, northeast of Batesville, Independence County. The rock is a gray, almost pure calcium carbonate that resembles a limestone rather than a marble, except that it takes a good polish. It occurs in beds 3 to 5 feet thick and is used chiefly for exterior building.

Black marbles of Mississippian age outcrop on the north slope of the Boston Mountains. Several quarries have been opened west of Batesville, Independence County; they produce a stone marketed as Arkansas Black. A coarsely crystalline gray marble was quarried near Guion, Izard County, years ago. Production in recent years has been confined principally to the gray marbles of Independence County, which are used for both interior and exterior building.

California

Marble deposits are numerous in California. Deposits have been noted in at least 28 counties, but most of them are small or inaccessible. In many places the rock is so shattered by earth movement that large, sound blocks are unobtainable.

Marble of many colors has been produced near Lone Pine, Inyo County. A quarry near Volcano, Amador County, has been operated intermittently. Pink, yellow, and gray varieties occur near Columbia and Sonora, Tuolumne County, in a marble belt about 150 feet wide. Although large, sound blocks are obtainable, recent production has been confined to chips for terrazzo flooring. California marble has been used for interior building and for monuments, but there has been little activity in recent years.

Colorado

Marble has been quarried extensively on Yule Creek near Marble, northern Gunnison County, about 10,000 feet above sea level. The marble occurs in massive beds at least 100 feet thick, with widely spaced joints that permit large, sound blocks to be quarried. Varieties are white, faintly clouded, and golden-veined. A large mill was operated at Marble. Owing to transportation difficulties, the deposit has not been worked for many years. This quarry supplied marble for the Lincoln Memorial in Washington, D. C., and the superstructure of the Tomb of the Unknown Soldier in Arlington National Cemetery.

Colored onyx marble is produced in small quantities at Canon City, Fremont County. The marble was quarried extensively for decorative uses in past years.

Georgia

The principal marble areas of Georgia are confined to Pickens County in the north-central part of the State. The chief belts extend from Tate to a point beyond Marble Hill, a distance of 4-1/2 miles. The valley of Long Swamp Creek, 1/2 mile east of Tate, contains a wide bed of marble. On the west side are the Creole, Cherokee, and Silver Gray quarries. The Etowah quarry is in the center of the bed. The silver-gray marbles are sold chiefly for monuments. Dark-clouded varieties from the Creole quarry are suitable for interior decoration and monumental use. The Light Cherokee quarry, which is very large and deep, furnishes several shades of light- and dark-gray, coarsely crystalline, translucent marbles for both interior and exterior use. The nearby Mezzotint quarry supplies stone for interior decoration. Marble from the Etowah quarry is unusual. It has the coarsely crystalline structure of Georgia marbles but is characterized by green veinings and various delicate shades of pink, which have been attributed to the presence of finely divided particles of hematite. However, spectrographic analyses made at the University of Tennessee in 1956 showed no significant differences in the iron and manganese contents of the white, gray, and pink Georgia marbles.

Other important quarries are near Marble Hill, 3 to 4 miles east and northeast of Tate. Most of these workings are in a narrow, high-walled valley through which flows the east fork of Longswamp Creek. The marble is coarse-grained and translucent. Tremolite and phlogopite occur as accessory minerals in places. The Marble Hill quarries furnish white and clouded marbles. The Rosepia quarry, no longer operated, supplied small blocks of a finer grained marble than that found in most Georgia deposits. The Amicolola quarry furnished blocks of unusually large size, but the quarry is not in operation now.

The Georgia marble beds are 185 feet or more thick, and the reserves are extensive.

Light- and dark-green verd antique marbles in attractive patterns are produced near Holly Springs, Cherokee County. Recently a black marble veined with white has been quarried at Ranger, Gordon County.

The light-colored Georgia marbles contain 93 to 99 percent calcium carbonate, have high strength and low absorption, and are used for exterior and interior building, memorials, and sculpture. A notable example of their use for sculpture is the heroic figure of Abraham Lincoln, carved by Daniel Chester French, in the Lincoln Memorial, Washington, D. C.

The bulk of the marble output is manufactured into finished products in large mills. Some is sold as rough blocks and slabs to independent mills throughout the country.

Quarries also produce terrazzo chips, roofing granules, and a ground product (marble flour). Marble flour is used extensively as whiting; as a constituent of paints, plastics, rubber, chewing gum, and stock feed; and for many other purposes.

Maryland

White marble was quarried extensively years ago at Cockeysville, Baltimore County. Large quantities were sold for use in buildings. Lower grades were used extensively for residential doorsteps, a characteristic feature of Baltimore. Recently the area has produced crushed and ground products only.

A large serpentine area extends from the Susquehanna River near the Maryland-Pennsylvania border southwestward through Harford County into Baltimore County. Extensive mining at Cardiff, Harford County, yields a dark-green, veined serpentine - a typical verd antique - which is sold for interior construction and decoration. The chief output, however, is terrazzo chips.

Massachusetts

White to gray dolomitic marbles were quarried some years ago near Lee, Berkshire County, and verd antique was mined near Springfield, Hampden County. No marble has been produced recently from either area.

Missouri

Marbles occur in widely scattered area in Missouri. Chief production comes from Carthage, Jasper County. The marble is in heavy, coarsely crystalline beds of Burlington (Lower Carboniferous) age. It is white to light gray and uniform in texture and color. Although well crystallized, the marble shows little or no evidence of folding or distortion. Like Tennessee marble it has stylolites or suture joints that parallel the bedding and are 2 to 20 inches apart. Stylolites are common in marble used for interior construction, but marbles for memorials and other exterior use contain only very fine stylolites. The marble takes a good polish and is used chiefly for interior work. A smaller quantity is used for exterior building and memorials. A mill is operated in conjunction with the quarry.

Marble quarried at Phenix, Greene County, belongs to the same geologic age and resembles the Carthage stone in many respects. Stylolites range is size from fine markings to wavelike zones 3 inches wide. In places the rock is fossiliferous. Sawed and cut marbles for interior use are the chief products.

Marble of the Kimswick formation, which is much younger geologically than the Burlington, is quarried in eastern Ste. Genevieve County. Fossiliferous, golden-vein and rose types are well adapted to interior decoration. The walls of the elevator lobbies in the Department of Commerce Building, Washington, D. C., are good examples of such use.

Marble quarried in Jefferson County is used chiefly for terrazzo chips, roofing granules, and similar products.

New Jersey

A light-green verd antique with attractive veining occurs near Phillipsburg, Warren County. It is quarried chiefly for terrazzo.

New York

Block marble was produced in New York years ago, notably at Plattsburg, Clinton County; Gouverneur, St. Lawrence County; and Wingdale, Dutchess County. Current activity in marble quarrying is confined to Westchester County, chiefly near Thorwood, where the stone is crushed to chips for terrazzo, stucco, cast stone, and roofing granules and ground to a powder for whiting, asphalt filler, and other uses.

North Carolina

Commercial marble developments in North Carolina have been confined to a belt 1,600 feet to nearly 1/2 mile wide extending across Cherokee County. The earliest operations were near Murphy and Regal, but close and irregular jointing in the marble beds discouraged quarrying in these areas. Recent production has been from the vicinity of Marble, where the joints are more regular and more widely spaced. Two types of marble are produced - a dark bluish gray, some of which is streaked and mottled with white, and a more or less uniform gray. Some of the output is sold for exterior building use but most of the output is memorial stone.

Puerto Rico

Deposits of marble are found in many areas in Puerto Rico. A mottled white marble occurs extensively near Juana Diaz, northeast of Ponce, near the south coast; a black marble with white veins outcrops 3 miles north of Cidra; and a gray marble intersected by wavy bands of red outcrops on a cliff face near Rosario toward the western end of the island. All Puerto Rican marbles take an excellent polish. Equipment was being assembled in 1956 for establishing a marble producing and fabricating industry.

Tennessee

The marbles of east Tennessee occur in the Holston member of the Chickamauga limestone of Palaeozoic age. The Holston beds of the Tennessee River Valley outcrop in a series of nearly parallel belts in an area 12 to 16 miles wide and 125 miles long. Knoxville and Concord are near the center of the region.

Tennessee marbles range in color from gray through various shades of pink to red. They consist essentially of calcareous remains of two types of marine organisms, crinoids and bryozoa. The marbles are not greatly deformed; in many beds undistorted fossils are plentiful. Most of the beds, however, tilt at more or less steep angles. A characteristic feature of Tennessee marble is the presence of stylolites, locally called crowfoot. These irregular or zigzag markings occur in bands 1/10 to 1 inch wide, generally parallel the bedding, and are a few inches to several feet apart. Tennessee marble has been used for steps, floor tile, and wainscoting in innumerable public buildings through the country. The marbles are notably pure, having a calcium carbonate content approaching or exceeding 99 percent. They also have low porosity. Tests at the National Bureau of Standards show an average of about 0.5 percent of pore space, and in some marbles the pore space is considerably less.

The bulk of the output in recent years has come from Blount, Knox, and Union Counties. The principal quarries of Blount County are near Friendsville. The beds dip generally about 30°, but north of Friendsville they are nearly flat lying and outcrop widely. Most of the marbles are pink, but the so-called New Tennessee Marble, produced in small quantities, is a light-gray, mottled dolomite of the Knox group lying below the Holston marbles. Below the Knox dolomite dark beds in Grainger County yield black marble used entirely for interior decoration.

The Knox County marbles are quarried extensively near Knoxville and Concord. Several companies operate quarries, and their mills produce a wide range of marble products. Colors range from gray to pink.

The largest Union County operations are near Luttrell. The marble bed in this area is about 75 feet thick, and dips about 32°. Colors range from light to dark red.

Marble products are fabricated in many well-equipped mills in the district. Rough blocks are also shipped to independent mills in various cities.

Tennessee marble is used chiefly for interior building, but substantial quantities are used for exterior work. A notable example of the latter use is the National Gallery of Art in Washington, D. C. Smaller quantities are used for memorial stones. Terrazzo and other crushed and ground products are made from quarry and mill waste. More waste marble is being used for house veneer. Blocks are first sawed, then split with a power-operated blade known as a guillotine.

Texas

The only marble-quarrying activity reported in Texas in recent years is production of terrazzo and roofing chats at Austin, Travis County.

Vermont

The western marble belt of Rutland County is about 80 miles long and 1/4 mile to 4 miles wide. It lies chiefly between the Green Mountains and the parallel Taconic Range to the west. A parallel occurrence of marble known as the West Rutland belt is about 6 miles long and 1/2 mile wide. Because of powerful crustal contraction and movement, the original horizontal limestone beds were crystallized into marble and, at the same time, folded into anticlines and synclines. During succeeding ages the crests of the folds were eroded away, leaving the marble exposed in long more or less steeply dipping belts. Records of drill cores and data from sections at the quarries show that the thickness of the marble ranges from 335 to 850 feet or more.

In most of the region a definite succession of workable beds may be traced. The entire succession is present in few, if any, localities. Each bed has its characteristic marble, which the quarrymen recognize and can trace from place to place.

The major joints generally are systematically arranged and are spaced so widely that large blocks can be obtained. Commercial marbles that abound throughout the belt are very pure; many contain 98 to more than 99 percent calcium carbonate. Their porosity is low, and their colors are white to cream, bluish gray, green, clouded, and mottled.

Following are the principal quarry locations, beginning at the southern end of the belt. A white to faintly cream, semitranslucent marble is obtained from extensive workings near Danby on Dorset Mountain. The amphitheater in Arlington National Cemetery was built of stone from this area. Similar marbles are quarried at Clarendon.

At West Rutland the marble structure is a truncated anticline, and the quarries fall in two groups - those on the western limb and those on the eastern. Several large quarry openings have been made on the western limb; these supply white and colored marbles, chiefly for interior use. Figure 2 shows one of these quarries.

The eastern limb of the fold at West Rutland is the most productive marble area in Vermont. Quarries extending more than a mile along the strike of the fold include the well-known Covered quarry, an underground operation 400 feet deep and 1/4 mile long. The various beds in these quarries furnish white, bluish, greenish, and pink architectural marbles.

Bluish white marbles mottled with gray are quarried near Proctor, Pittsford, and Florence. The Pittsford Valley quarries are noted for the large, sound blocks obtainable. A typical stone quarried at Brandon toward the northern end of the belt is a light bluish gray marble having a mottled appearance owing to the recurrence of fine, gray, plicated beds.

Marbles occur in certain areas in Vermont outside of the western belt. Reddish, or mottled red and white, siliceous so-called Champlain marbles are quarried near Swanton, Franklin County. Because of their high resistance to abrasion, they are particularly well adapted for floor tile and stair treads.

A marble, the polished surface of which is almost black but is interspersed with characteristic white circular fossil casts, occurs on Isle La Motte in Lake Champlain, Grand Isle County. Verd antique marbles are obtained at Roxbury, Washington County, and Rochester, Windsor County. Large sawing and finishing mills are operated at West Rutland, Center Rutland, Florence, Proctor, and elsewhere. Vermont marble is used for exterior and interior building and decoration, for monuments, sculpture, and miscellaneous purposes.

Virginia

A marble that is black when polished is quarried near Harrisonburg, Rockingham County. Recent production consists chiefly of terrazzo chips.

Washington

Marbles in a variety of colors, including red, pink, white, and black, are quarried near Chewelah, Stevens County. The output consists of terrazzo chips and similar products.

Foreign Deposits[3]

Marbles are quarried in many countries. Details of their occurrence and production have been published (8), and only those of greatest interest to marble users in the United States are considered in this report. Many foreign marbles are in demand because their colors and patterns have no counterparts among marbles produced in America.

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[3] Much information on foreign marbles was supplied by B. A. Calonna, president, Calonna & Co., Long Island City, N. Y.

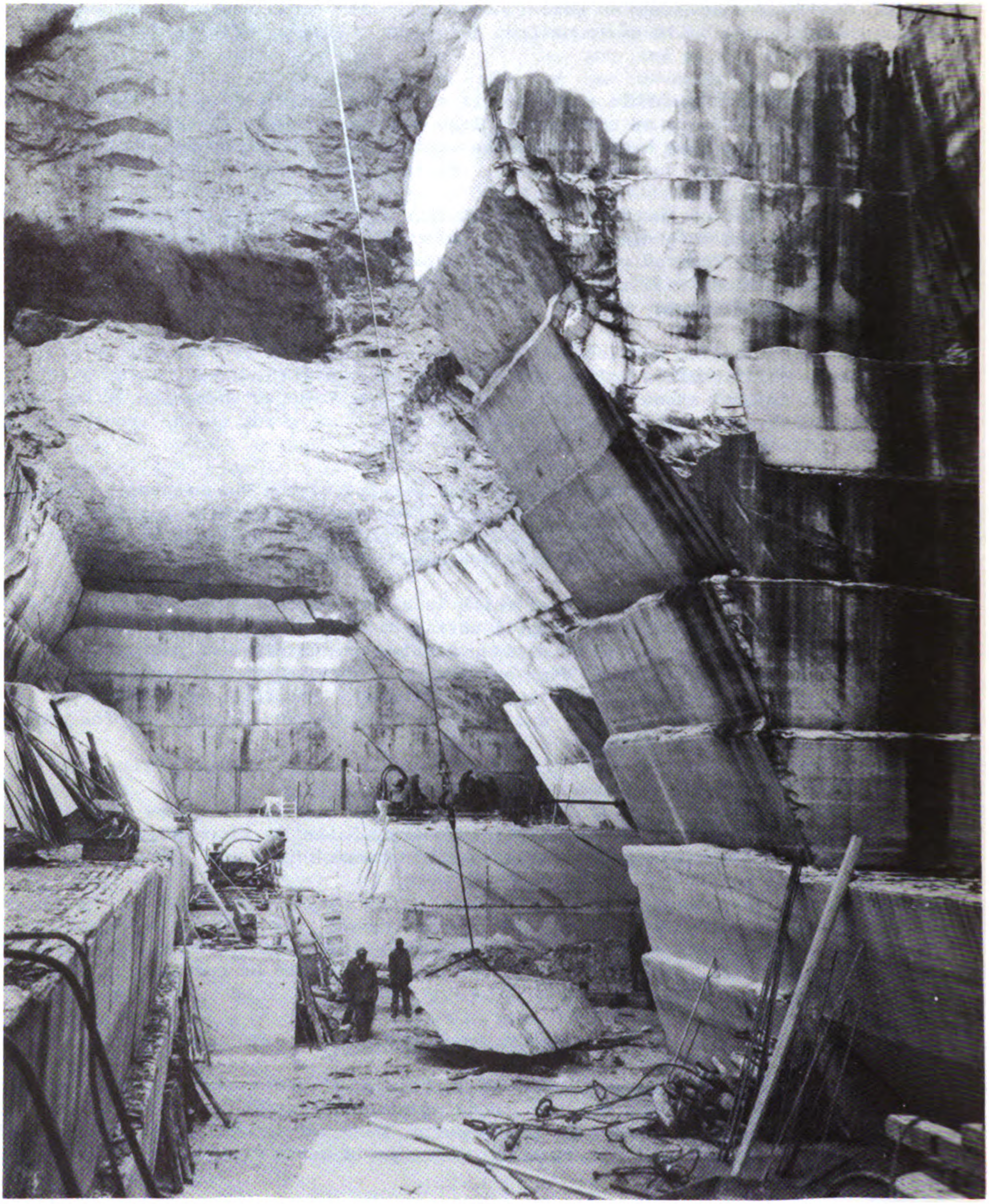

Figure 2. - Marble quarry in Vermont.
(Courtesy, Vermont Marble Co.)

Italy

Italy has been renowned for its marbles since the days of the Roman Empire and is still a leading world producer. The best-known Italian marbles on the American market are the many varieties of white marbles from Carrara and vicinity. The famous Carrara district lies between Genoa and Pisa; quarries were first worked in the district about 283 B. C. Approximately 10 percent of the output is classed as statuary grade, 75 percent in numerous grades of white with gray veins or spots, and 15 percent in colored and brecciated grades. The Siena marble district lies in central Italy between Florence and Rome. A leading variety is Brocatello di Siena, a deep yellow with dark veins. As travertine is included with commercial marbles, mention should be made of the famous Roman travertine quarries which supplied blocks for the Coliseum in Rome and from which large quantities of blocks are shipped to the United States and other countries. The deposits are near Tivoli outside of Rome. Green marbles (serpentines) are obtained from Val D'Aosta in the north of Italy and from Van Malenco near Lake Garda. The well-known Botticino and the colorful Loredo are quarried at Brescia. Recently considerable cream-colored Dolcetto Perlato has been shipped to the United States from Trapani, Sicily.

A recent publication describes Italian marbles in greater detail (9).

France

France has many varieties of marble, but several quarries have not been reopened since World War II. The St. Michel and Bellejoyeuse are well-known gray marbles from Arudy in the Basses-Pyrenees. The Pyrenees also yield the Rouge Antique, Rosso Merlino, and other red varieties and a variety known as Escalette. The Rose de Brignoles, from Toulon, and the Hauteville, from near Grenoble, are now available.

Belgium

The Belgian marble best known in the United States is Belgian Black (Noir Belge), which is regarded as the finest black marble in the world. It is obtained from extensive underground operations northwest of Namur. Blue Belge is a variety having white veins. A wide variety of red marbles with white veining, known as Belgian Red or Rouge Royal, is obtained from deposits in the Forest of the Ardennes.

Greece

The best known Grecian marbles are the Parian, obtained on the Island of Paros in the Grecian Archipelago, and the Pentelic, quarried on Mount Pentelicus near Athens. A shipment of the latter was received recently in the United States. Cipolino, a popular marble in the United States, contains alternate bands of white and pale green and was so named because of its resemblance to an onion cut in half. Another popular marble, quarried on the Island of Tinos in the Aegean Sea, is green with white veins. Verde Antico, a brecciated green serpentine, probably was the first verd antique marble quarried in the world.

England

The only marble imported in quantity from England at this time is the Renfrew, which has a black or dark-gray fossiliferous groundmass veined with red. It is obtained from the Ashburton quarry near Torquay, Devonshire.

Spain

Spanish marbles are becoming increasingly popular in the United States. Quarries near San Sebasian and Bilbao in northern Spain furnish Negro Marquina, a black marble with white veins; Rose and Gray Alhambra, a mixed-gray and light-red marble; Catalan Red, which resembles Belgian Rouge Royal; and several other varieties. In southern Spain, quarries near Valencia and Alicante furnish Rojo Alicante, a medium-light-red marble with white veins, and buff Ivory Vein, a marble intersected with golden veins. A dark-brown onyx marble, much in demand for desk sets, tabletops, and special building decoration, is obtained from deposits at Malaga.

Portugal

Among the popular Portuguese varieties are white marbles with rose veinings, from Vila Vicosa near the Spanish border, and St. Florient Rose, from the Pero Pinneiro district north of Lisbon.

Germany

German marbles, unavailable during World War II, are being imported into the United States in increasing quantities. The best-known varieties are the Famose, the Vert Corail, and the many colored marbles from Bavaria. A veined, brownish yellow, so-called German Siena travertine is quarried at Cannstadt.

Scandanavia

Norway furnishes Norwegian Rose, a white marble with rose markings and light-green veins, and Sweden the Swedish Green or Swedish Cipolin, a light-green marble with white veins.

Africa

Some of the most famous marbles of antiquity were quarried in northern Africa by the Carthaginians and later by the Romans. Unfortunately, the beautiful red and yellow Numidian marbles have not been produced since World War II, when the road to the quarries was destroyed. The prized Rouge Flamme Onyx is still produced near Oran, Algeria. Marble exports have increased greatly since World War II, chiefly from the vicinity of Rabat and Casablanca. The principal varieties are the Platina Rose; Moroccan Gray, with white veins; the Lido, gray with darker veins; and the African Skyros, which resembles marble from the Greek Island of Skyros. The last-named marble is not in production at this time.

Mexico

The most famous onyx marbles in the world are those produced at El Marmol, Lower California, about 330 miles southeast of San Diego, Calif. Some beds furnish block onyx that may be sawed into slabs for interior decoration in banks, hotel lobbies, and theaters and for soda fountains. Smaller blocks are fashioned into novelties such as book ends, pen sets, ashtrays, etc. Substantial quantities are imported into the United States.

QUARRY METHODS AND EQUIPMENT

Stripping

The term "stripping" applies to removing soil or other debris that overlies marble beds. If workable marble appears in bare outcrop, little or no stripping may be necessary. The methods and equipment used depend upon the depth and nature of the overburden. Under favorable conditions, the hydraulic method is probably the most economical. A powerful stream of water directed by a nozzle or monitor simply washes the soil away. The removal of a heavy overburden, even as much a 40 or 50 feet, is relatively simple with modern types of massive, earth-moving equipment.

Quarry Plan

The plan of quarry operation is influenced largely by the thickness and attitude of the marble beds. If the beds are flat lying and relatively thin, the quarries will tend to be wide and shallow. This condition is unusual because most marble beds dip at steep angles. Steeply dipping beds may be worked from open pits developed along the direction of strike. If the beds are thick, open-pit mining may suffice for years, but eventually underground operation may become necessary.

Channeling

The first step in quarrying is to separate marble blocks from the parent ledge, which must be done with care. Explosives might shatter the rock so that it would be valuless; methods must be employed that will preserve the integrity of the blocks.

Primary cuts are usually made with a channeling machine which operates with a chopping action similar to that of a reciprocating drill. The cutting tool comprises several chisel-edged steel bars clamped together. As the machine travels back and forth on a track, it cuts a channel 2 to 2-1/2 inches wide and several feet deep.

The natural jointing of the rock, as described earlier under the discussion of physical properties, is of primary importance in quarrying. If joints occur in parallel systems, the major joints furnish natural partings; and, if they are conveniently spaced, channel cuts may be required only at right angles to them. Where joint systems permit, channel cuts are made at right angles to the direction of rift to take advantage of the direction of easy splitting in making cross breaks by drilling and wedging.

If the quarry floor is level, track laying is simple. If the beds are inclined, it may be necessary to quarry each bed separately to maintain uniformity. The removal of right-angled blocks from successive inclined beds results in a notched or saw-toothed quarry floor, which necessitates construction of elevated tracks for the channeling machines. An easier method of cutting dipping beds is to place the channeling-machine track on the inclined rock surface in the direction of dip. The force of gravity which tends to pull the machine downhill is overcome by use of a balance weight.

Wherever possible, primary cuts should follow directions parallel and at right angles to joints in order to minimize the number of joints or cutters that intersect blocks. Following this procedure gives a maximum number of sound blocks. If joints are irregular, closely spaced, of meet at oblique angles, excessive quarry waste cannot be avoided.

Wire Sawing

The wire saw has become an important tool for cutting stone. It consists of a 1- or 3-strand wire rope about 3/16 inch in diameter, which runs as a belt and cuts by abrasion when fed with sand or other hard grains in water. It is used successfully in slate, limestone, and granite quarries in the United States and in marble and other quarries in Europe; however, it has been used very little in American marble quarries. In view of the remarkable success attained with this equipment in cutting granite, a rock twice as hard as marble, as described in a recent Bureau of Mines report (12), it seems strange that United States marble quarrymen have found no means of overcoming operating difficulties.

Drilling

Some channeling is regarded as necessary to obtain clearance for block movement and removal, but rock masses usually are separated by drilling and wedging because it is less costly than channeling. The drilling and wedging method is used almost invariably for making horizontal floor breaks.

Compressed-air hammer drills are generally used. A bar drill is used for sinking vertical holes in rows. A horizontal bar is supported by a pair of steel legs at each end. A hammer drill mounted on the bar can be moved to any position by means of a pinion working in a rack of cogs. A bar, adjustable for height, can also be used for making holes in horizontal rows in a bench face. A gadder is a bar held in vertical or inclined position on which a drill is mounted for making horizontal holes in the face, wither in vertical or inclined rows. Rows of drill holes generally follow the direction of rift or grain of the marble. Spacing ranges from 4 inches to 2 feet, depending upon the ease of splitting.

Drilling and Broaching

Drilling is sometimes substituted for channeling. By means of a bar drill, sometimes called a line drill, closely spaced holes are drilled in line, and the webs or cores between them are removed either by drilling or by using a broaching tool in place of the drill. This method of cutting a channel is used more in granite than in marble quarrying, but its use for quarrying marble is gaining favor.

Wedging

Blocks are separated by driving wedges in drill holes, using the so-called plug-and-feather method. Feathers are two half-round strips of iron, flat on one side for contact with the wedge and curved on the other to fit the wall of the drill hole. The plug is a steel wedge which is driven between the feathers. The plugs are sledged lightly in succession, beginning at one end of the line to maintain an even strain on the rock. Sledging is continued until a fracture appears. A pronounced rift is advantageous in wedging as it allows a comparatively wide spacing of drill holes.

Making Floor Breaks

Before blocks can be subdivided by wedging, they must be broken free at the quarry floor. In opening a new quarry bench, the first block to be removed is known as the key block. Its removal is difficult because no face is available from which to work. After channels are cut on four sides, a floor break is made by placing slanting iron plates in the bottom of one channel cut and driving wedges between the plates and the bottom edge of the key block. A horizontal rift assists greatly in making such a floor break. After the key block has been removed, space is available for mounting drills and drilling holes in which wedges may be driven to make floor breaks beneath adjacent blocks.

Underground Operation

Steeply inclined marble beds may be worked from open quarries near the surface, but as the beds are followed to greater depths underground operation becomes necessary. In underground work the most difficult step is to drive an advance heading at the roof. This is done by making channel cuts in the face of a heading dipping 20° or 20° and by blasting the rock with light explosive charges in drill holes above and below the channel cut. The broken rock is removed and the process repeated. A line drilling and broaching method has recently been substituted for blasting. When floor space is adequate, chanmeling machines can be set on the floor and operations conducted as in an open quarry. Pillars are left at intervals for roof support.

Undercutting

Undercutting is a modification of underground operation. The quarry floor is enlarged by an outward inclination of the wall cuts. The process is simple, requiring no additional equipment and no costly preliminaries; however, there are some disadvantages. In underground operation projection of the preliminary roof heading is costly and may produce only waste rock, but once this is done operations are conducted with almost as much ease as in an open quarry. In undercutting, however, every wall cut is slanting, and chanmeling at an angle is slow and relatively costly. Moreover, the blocks of the outer rows are angular, resulting in waste.

Hoisting

When a block of marble is separated from the bed, the next step is to hoist it from the quarry. Hoisting is generally done with powerful guy derricks. Masts and booms may be of wood but are usually of steel. Derrick guys are anchored by angle steel bars set in concrete, waste blocks of stone, or a "deadman" made of large logs. Lifting capacities may be 15 to 50 tons or more.

Cables may be attached to blocks by grabhooks (grapples), chains, or cable slings. Slings are preferred by many operators, as they are safe and easily handled.

Scabbling

The term "scabbling" is applied to trimming marble blocks to true size and shape. If the blodks are to be milled close to the quarry, the process may be omitted. If the marble is to be conveyed a considerable distance of sold in block form, scabbling is desirable, as it reduces the cost of transporting waste material. The crudest method of scabbling is by manual labor with a scabbling pick. Irregularities may be scabbled by drilling and wedging, but wire sawing is regarded by many marble men as the most efficient method because several blocks may be lined up and trimmed simultaneously.

Transportation

In some regions mills are so close to quarries that the derrick may be used to place the blocks on mill transfer cars; however, haulage by rail or truck is usually required. Trucks have replaced railroad cars in many quarries. Block storage yards may be maintained. Blocks of marble are placed in storage and removed from storage by overhead traveling cranes. The use of mobile cranes, mounted on rubber tires or crawler treads, is becoming more widespread around quarries. Use of the straddle truck for moving blocks of marble is also increasing.

EQUIPMENT AND OPERATION IN MILLS AND SHOPS

Most marble quarries have plants associated with them for sawing, polishing, carving, or otherwise preparing marble for structural, ornamental, or memorial use. In the mill the blocks are sawed into slabs; all other finishing is classed as shopwork. Where both sawing and shopwork are done, the mill and shop are generally close together.

Mill Sawing

Marble is cut into slabs with gangsaws. These saws comprise a series of iron blades set parallel in a frame that moves backward and forward. When fed with sand or other hard, granular material in water the blades cut by abrasion. The thickness of slabs is governed by spacing of the blades. The frame moves downward by screw feed, and the rate of movement can be adjusted for harder or softer rock. Sand is generally employed as the abrasive, but faster sawing may be obtained with chats, steel shot, or crushed steel. Where marble blocks are cut into slabs approximately 1 inch thick, a gang may have 40 to 50 blades about 1/8 inch thick which make cuts about 3/16 inch wide. The rate of sawing depends upon the hardness and uniformity of the marble. Many marbles contain relatively hard knots of siliceous minerals that are harder to saw than pure marble. Such knots tend to divert the saw blases, causing uneven surfaces that require additional processing in successive stages of grinding and polishing. However, if the rate of downward movement of the saw blades is reduced when hard knots are encountered, the saw will cut its way through the knots with little or no diversion from its straight course. One saw attendant usually serves as a listener. He can recognize a change in the sound of the saw when a hard knot is encountered and can immediately reduce the rate of downward movement until the saw has passed through the hard area.

If smooth, even surfaces are desired, a slow rate of feed is maintained; it may not exceed 3/8 inch per hour. Blades can easily cut average marble at twice that rate, but the resulting surfaces tend to be rough an uneven.

A transfer and gang-car system is generally used to save time in handling blocks and slabs. The transfer car, which runs on a depressed track in front of the gangs, is provided with a short section of track across the top. A gang car loaded with a block of marble is placed on this track and, when moved into position, is shifted under the gang. Similarly, a gang car loaded with finished slabs may be moved quickly from beneath the saws to the transfer car for transportation to the shop.

Figure 3 shows a convenient arrangement of mill and shop. One overhead traveling crane unloads blocks brought to the mill by rail or truck and either piles them or loads them on transfer cars. A track passes down the center of the mill with gangsaws on both sides. Transfer cars on this track supply blocks as needed to the various gangs and remove carloads of slabs to the shop which adjoins the mill. A smaller overhead traveling crane at the end of the shop handles slabs and loads finished products on cars or trucks.

One company is now using a wire saw to cut slabs. The wire is said to cut faster than the gangsaw and to leave a smoother surface.

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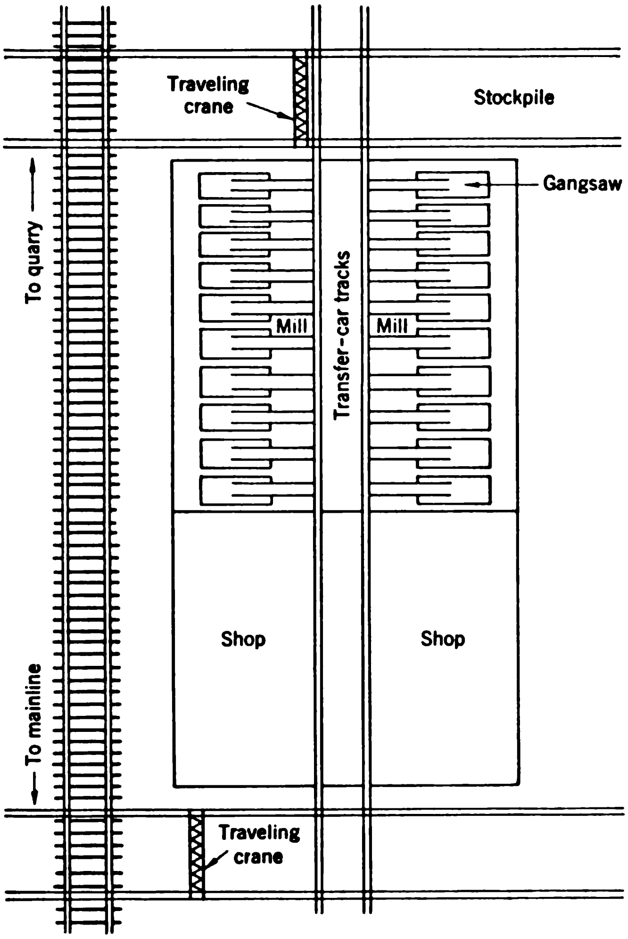

Figure 3. - Track arrangement for marble mill and shop.

Coping and Jointing

When sawed slabs reach the shop the first operations are coping and jointing. Both terms are used to mean subdividing marble slabs into smaller sizes. Coping is the process of cutting a slab into two parts without regard to finishing the edges. In jointing, however, the edges are true and square with the face and without chipped corners. Silicon carbide wheels, formerly used for jointing, have been largely replaced by diamond wheels.

Rubbing

Slabs and blocks that are not true to size are squared and finished on a rubbing bed - a circular disk of cast iron, 10 to 12 feet in diameter, rotating on a vertical axis. Marble slabs or blocks held on the surface of this rotating disk, to which sand and water are applied are worn down to desired dimensions and smoothness. These machines are now being supplemented by electrically powered steel laps supplied with a water-abrasive slurry which is circulated over the marble surface.

Gritting and Buffing

Gritting gives a smoother surface than rubbing. It is generally done with abrasive bricks attached to revolving buffer heads which travel over the surface. The bricks are of silicon carbide or aluminum oxide of different degrees of fineness, depending upon the finish desired. Gritting furnishes what is known in the trade as a hone finish. A new automatic type of surfacing machine is equipped with silicon carbide or diamond rotating heads.

Buffing, the process that gives the final polish to marble, is done by guiding a rotating buffer head of felt or other soft-textured material over the wetted surface of the marble. Putty powder, consisting of tin oxide or a mixture of tin oxide and oxalic acid, is used as the abrasive. (See fig. 4.)

Shop Sawing

Although saws of various types may be used in shopwork, the circular diamond saw has superseded most other types. The first cost of the diamond saw is high, but with care the maintenance expense is moderate. It cuts rapidly and leaves a smooth

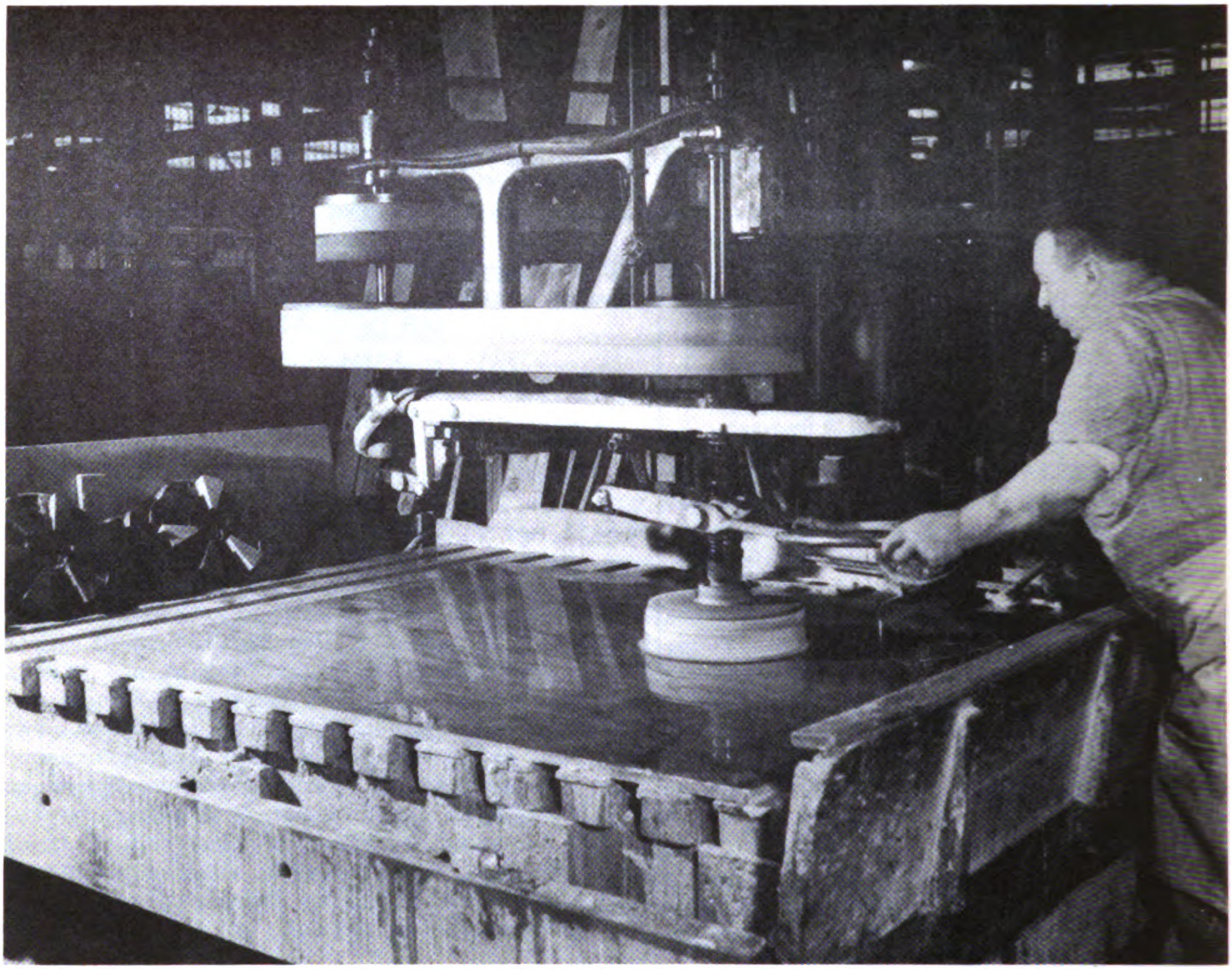

Figure 4. - Polishing marble with buffer.
(Courtesy, Vermont Marble Co.)

surface. An abundance of water must be supplied to the cutting edge, and care must be exercised to avoid overcrowding. Peripheral speeds are about 10,000 feet per minute.

Planing

Planers are sometimes used for cutting moldings and cornices. The planer tool is stationary except for lateral and vertical adjustment. The marble slab is carried beneath it on a traveling bed or platen. The surface is scraped to the desired thickness and shape.

Machining with Carborundum Wheels

Silicon carbide is a useful abrasive for shaping marble products. Carborundum wheels run at high speed, and an abundant supply of water is directed upon the cutting edge or surface. These wheels are capable of various adaptations for cutting moldings, cornices, and balusters. The wheel is a negative of the desired pattern. The marble travels on the machine bed beneath the wheel. In cutting balusters the marble and the wheel are brought into contact while both are rotating. The marble rotates slowly, whereas the wheel may have a peripheral velocity as high as 5,000 feet per minute.

Column Cutting

Marble columns are widely used in architecuture. They comprise two types - sections set one upon another and monolithic columns. Sectional columns are generally cut with steel drums rotating on a vertical axis. Sand or steel shot may be used as cutting agents, or the lower edge of the drum may be mounted with diamond teeth. For monolithic columns a lathe is used. The column is roughed out to approximate dimensions before it is placed in the lathe. As the column rotates, it is shaped with a tool similar to that used on an ordinary machine lathe for turning metal shafts. Actuated by a worm gear, the tool travels back and forth, cutting a little deeper at each motion until the desired diameter is reached. This process is followed by rubbing and polishing.

To make fluted columns the stone is first turned in a lathe to the desired diameter. While the column remains stationary in the lathe the cutter, held in the tool post, travels back and forth from end to end of the column until a groove is completed. The column is then turned to new positions and the process repeated until all the flutes are made. Flutes are sometimes cut with carborundum wheels.

Lettering and Other Carving

Complicated patterns and irregular designs may be shaped with abrasive wheels, planers, or pneumatic tools. Inscriptions and ornamental designs are cut chiefly by sand blasting. The surface of the marble is covered with a rubberlike dope, which is removed from the parts that are to be cut below the surface. Sand, silicon carbide, or other abrasive in granular form is then driven against the surface through a nozzle at high pressure. The exposed surfaces are cut to the desired depth very quickly, but the abrasive has little or no effect upon the dope. Sand blasting requires a mere fraction of the time that would be needed for carving with tools.

Waste in Quarrying and Manufacture

Even if quarrying is conducted with care to avoid imperfections and to make cuts that conform with joints and other rock structures, considerable waste in unavoidable. Recovery of usable stone is usually less than 50 percent of the gross quarry output. Sawing, planing, cutting, and carving in the mill and shop result in further waste. The piles of unused rock also create disposal problems.

In order to obtain some return on waste, quarry and mill operators try to develop byproduct markets for waste. Fortunately, marble has the same chemical composition as limestone, which has extensive and varied markets. The leading commercial marbles of the United States contain calcium carbonate high enough in purity to satisfy the requirements of the chemical and metallurgical industries.

Important crushed-marble products are terrazzo chips used extensively in flooring and chips for stucco wall finish. Waste blocks may be cut into convenient sizes for ashlar used in increasing quantities in house construction. In some places, waste marble is manufactured into lime. It is also ground to an impalpable powder (marble flour) for use as whiting and as a constituent of stock feed and fertilizers. It is sold as agricultural limestone, for chemical and industrial uses, and in crushed form for concrete aggregate and roadstone. Its chief handicap is location.

Even high-grade crushed limestone and marble are relatively low-priced products that will not bear heavy transportation costs, and the larger marble-producing centers are remote from most metallurgical and chemical industries that consume substantial quantities of limestone. At times, highway and other construction projects furnish market outlets adjacent to marble quarries.

MARKETING (4)

All high-grade marbles have a nationwide market. Marketing is complex, because there are at least five agencies for this purpose. First are the wholesalers who sell marble to the trade, chiefly as blocks or sawed stock. Second are the manufacturers who do not own quarries but buy marble blocks and make marble products; interior marble usually is both finished and set by them. Third are dealers or contractors who have neither quarries nor mills but buy finished marble and sell it, set in place, to customers. Fourth are producers who have quarries but no finishing mills or shops and sell their product in blocks to wholesalers or manufacturers. Fifth and largest are manufacturing producers who have quarries, mills, and shops and engage in all activities of the trade.

Marble in blocks and sawed slabs more than 2 inches thick is sold by the cubic foot; slabs 2 inches thick and less are sold by the square foot.

Marble is classified as to kind or variety, and frequently each kind varies enough to require separation into two or more grades.

Exceptionally beautiful and rare marbles are high priced but have a limited market; those of agreeable tone, texture, and finish, readily obtainable in large quantities, bring a fair price and have a wide market.

PRICES

As marble is generally sold on contract for individual projects, no market quotaions can be used as price indexes. Prices are best measured by quantities and values of sales, as reported each year to the Bureau of Mines by marble producers. Table 5 shows average values of sales of cut and finished marble in recent years.

TABLE 5. - Average price of rough and finished marble, 1944-56, per cubic foot

(Data from Bureau of Mines)

Year	Exterior building		Interior building		Monumental, rough and dressed
	Rough	Dressed	Rough	Dressed	
1944	$1.57	$9.10	$1.88	$7.91	$6.48
1945	1.70	4.63	2.24	8.42	7.15
1946	3.45	6.10	2.50	9.96	8.28
1947	4.33	11.12	2.72	11.55	9.74
1948	4.85	8.65	3.11	11.78	10.28
1949	3.98	9.13	3.47	13.70	10.37
1950	3.97	9.76	3.80	12.62	9.72
1951	4.08	9.31	3.65	11.82	9.25
1952	4.38	9.81	2.65	13.19	9.34
1953	4.13	7.94	3.31	13.14	9.33
1954	4.21	8.58	2.90	12.22	11.03
1955	3.33	9.82	3.97	12.34	9.23
1956	3.90	7.14	2.99	14.81	12.64

TARIFF

The United States Tariff Act of 1930 established an import duty on marble, breccia, and onyx in rough blocks of 65 cents per cubic foot and on sawed or dressed blocks, over 2 inches thick, of $1 per cubic foot. Slabs and paving tile were dutiable at 8 to 13 cents per superficial foot, with an additional charge of 3 cents if rubbed and 6 cents if polished. Mosaic cubes were dutiable at 1/4 cent per pound plus 20 percent ad valorem, if loose, and at 5 cents per superficial foot plus 35 percent ad valorem, if attached to paper or other material. Manufactured articles wholly or in chief value of marble were dutiable at 50 percent ad valorem.

The rates established by the Tariff Act of 1930 have been modified considerably by trade agreements. The duty on onyx, in rough or squared blocks, was reduced from 65 to 32-1/2 cents per cubic foot in trade agreements with Argentina, effective November 15, 1941, and Mexico, effective January 30, 1943. The duties on all other forms of marble, breccia, and onyx were reduced pursuant to concessions made under the General Agreement on Tariffs and Trade (GATT) as follows:

In blocks rough or squared only: The duty on black marble was reduced from 65 to 32-1/2 cents per cubic foot, effective January 1, 1948; duty on other marble and breccia was reduced to 32-1/2 cents per cubic foot, effective May 30, 1950. The duty on all marble and breccia was reduced further to 30 cents per cubic foot effective June 30, 1956, to 29 cents per cubic foot effective June 30, 1957, and to 27-1/2 cents per cubic foot effective June 30, 1958.

Sawed or dressed over 2 inches thick: The duty on black marble was reduced to 50 cents per cubic foot effective January 1, 1948, on other marble and breccia to 50 cents per cubic foot effective May 30, 1950, and on onyx to 50 cents per cubic foot effective November 17, 1951.

Slabs and paving tiles: The duty was reduced from 8-13 cents to 4-6-1/2 cents per superficial foot; the additional charge of 3 cents if rubbed was reduced to 1-1/2 and the additional charge of 6 cents if polished to 3. These reductions were effective May 30, 1950.

Mosaic cubes: The duty on loose cubes was reduced from 1/4 cent per pound plus 20 percent ad valorem to 1/8 cent per pound plus 10 percent ad valorem; that on attached cubes was reduced from 5 cents per superficial foot plus 35 percent ad valorem to 2-1/2 cents per superficial foot plus 17-1/2 percent ad valorem, effective May 30, 1950.

Manufactured marble: The duty was reduced from 50 to 25 percent ad valorem, effective January 1, 1948. The duty was further reduced to 23-1/2 percent ad valorem June 30, 1956, to 22-1/2 percent June 30, 1957, and to 21 percent June 30, 1958.

Unmanufactured travertine: Pursuant to concessions made under GATT the duty was reduced from 25 cents to 12-1/2 cents per cubic foot, effective May 30, 1950. The rate was further reduced to 11-1/2 cents as of June 30, 1956, to 11 cents June 30, 1957, and to 10-1/2 cents June 30, 1958.

Hewn, dressed, or otherwise manufactured stone (including travertine): The duty was reduced from 50 to 25 percent ad valorem, effective May 30, 1950. It was further reduced to 23-1/2 percent June 30, 1956, to 22-1/2 percent June 30, 1957, and to 21 percent June 30, 1958.

IMPORTS AND EXPORTS

Imports of marble, as indicated in table 6, have increased greatly in recent years. Marble exports are not shown separately in United States Department of Commerce trade statistics, but they are relatively small.

TABLE 6. - Marble, breccia, and onyx imported for consumption in the United States, 1944-56, by kinds

(Compiled by May B. Price from records of U. S. Department of Commerce)

Year	Sawed, over 2 inches thick		In blocks		Slabs or paving tile superficial		Other	Total
	Cubic feet	Value	Cubic feet	Value	Feet	Value	Value	Value
1944	-	-	2,487	$11,368	316	$409	$18,023	$29,800
1945	-	-	8,218	44,292	-	-	13,854	58,146
1946	1	$4	105,997	520,479	39,792	22,075	101,588	644,146
1947	21	77	169,812	703,311	83,739	30,345	99,115	832,848
1948	648	5,586	109,345	436,305	147,053	85,197	132,429	659,517
1949	1,521	8,935	130,331	590,202	208,709	129,884	201,301	930,322
1950	1,521	5,990	131,557	587,894	464,493	301,684	331,293	1,226,861
1951	1,960	13,729	175,106	805,453	647,780	436,702	419,844	1,675,728
1952	1,330	7,041	157,873	827,903	673,890	472,290	553,311	1,860,545
1953	538	3,905	175,550	912,643	957,592	713,093	1,042,985	2,672,626
1954	317	4,005	200,468	968,809	1,032,174	[1]665,886	[1]1,189,515	[1]2,828,215
1955	317	[1]6,639	222,363	[1]1,154,018	1,183,324	[1]842,242	[1]1,289,949	[1]3,292,848
1956	900	10,589	225,449	1,189,036	1,715,452	1,232,619	1,989,318	4,421,562

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[1] Owing to changes in tabulating procedure by the U. S. Department of Commerce data known to be not comparable with earlier years.

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